ARTSN: An Automated Real-Time Spacecraft Navigation System

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Introduction

A prototype effort was started in the Telecommunications and Mission Operations (TMO) Navigation Work area to demonstrate a new class of navigation software for automated real-time interplanetary spacecraft navigation (ARTSN). The motivation for the development of ARTSN is efficiency. This tool makes it possible for the navigation operations analyst to switch from a mode of constant oversight to exception monitoring, thus enabling him to support additional spacecraft, simultaneously. Also, the ability of the automated system to provide faster orbit solution generation, than manual systems, allows for a greater ability to support missions that have a short turnaround between the occurrence of a critical event and the generation of a required response to that event.

ARTSN Paradigm

Historically, all interplanetary missions have made use of ground-based radio metric data, such as Doppler and range. Additionally, some missions have made use of optical images of target bodies against a known star field, telemetered to the Earth for processing, to provide target relative position information. With all of these data types, the information is electronically transferred to a ground operations facility, where the data is buffered and stored until processed; the latency between observation time and processing time may be from as little as 10 minutes to as long as a few months (depending on the needs of the mission), with 12–24 hours being typical.

Newly received data is merged with already analyzed data and the entire data set is processed via a batch-sequential least squares estimator. In this process, the identification and deletion of invalid data as well as the operation of the software is performed by an analyst operating at a workstation console. The process of fitting the data requires the use of multiple software links and the manual examination of prefit residuals, to determine which points should be fit and which points should be deleted from the solution. After generating the best estimate of the spacecraft trajectory, based on the input models, the analyst must determine the appropriate set of output coordinate frames and mappings that are desired to view the solution and use the software to generate postfit residuals. Typically, this process requires approximately one hour of additional processing time after the data is received by the operations analyst. When it is necessary to evaluate multiple models, as is the normal procedure, multiple analysts must work in parallel, or additional processing time is required.

While recent missions have begun to institute greater automation of portions of the process, the nature of the automation focuses on the use of scripts and automated routines that use the underlying software instead of the development of a robust system intended for automated use. Although such automated systems have been developed for Earth orbiting missions, they have not previously existed for interplanetary missions. With such a system, one could automate the generation of predicted spacecraft positions for ground stations, provide an operational tool for fast turn-around applications, and become a 'stepping stone' to an onboard interplanetary navigation system.

Development History

The conceptual design of ARTSN began in 1994 at JPL. The resulting design, known as RTAF (Real-Time Automated Filter) [Ref.], brought out several key lessons learned:

- Modularize the architecture of the system whenever possible.
- Separate the data output and control user interfaces from the primary analysis system.
- Use commercial software when possible.
- Streamline the process for addition of new force and observable models.

From RTAF, the next step was to build the ARTSN prototype, with the short-term objective of demonstrating automated radiometric data processing for interplanetary cruise. From the lessons learned came two tenets of the ARTSN design:

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- Integrate the (historically) separate modules into a single package. Merging the links that provide trajectory propagation, station location computation, measurement modeling, filtering, and state and covariance mapping facilitate the real-time capability.
- Use modern software techniques to implement the existing algorithms. The resulting highly modular components can be modified easily and arranged to work in a distributed environment.

ARTSN Characteristics

Figure 1 shows the ARTSN components, as well as the data flow throughout. The interaction between the components is handled with machine portable data structures through TCP/IP network connections. The data preprocessor, known as ARTOG (Automated Real-Time Observable Generator), creates measurement records from the raw DSN TRK-2-15A stream. ARTOG performs simple data validation checks and supplies ramps and a time-ordered sequence of Doppler and range data. The ARTSN shell is a command-line style interactive user interface that translates namelist inputs into engine-remote procedure calls. The ARTSN engine is where the integrations, observable computations, filterings, and mappings are performed, separate from the user interface; thus, the input and output processes can be modified for specific projects and users without modifying the engine. The displays for this prototype are LabVIEW graphical applications; any package with a network interface (such as Java) can be used to create an ARTSN real-time display. By using remote procedure calls, the displays configure the engine to send the correct data stream back to them without user interaction directly with the engine. Front- and back-end displays can be implemented on relatively inexpensive desktop PCs while the engine runs on a workstation.

A feature of the ARTSN software architecture is the standardization of the module interfaces, which allows new modules to be added quickly by any programmer that adheres to the interface standard. Changes and additions can be propagated by using the interface; this helps eliminate unsupported programs and versions and allows for more efficient configuration management.

A third feature of the ARTSN architecture is the generic participant structure. A participant can be a spacecraft, ground station, or natural body. No assumptions are made on what participants exist, or what their relationships are to other participants. This enables support for scenarios with multiple spacecraft, asteroids with moons, comets, etc. This arbitrary participant structure enables:

- Multiple spacecraft simulations
- Measurements between any participants
- Mapping events between any participants
- Addition of new propagator types

ARTSN Use

(1) A preliminary validation of ARTSN was performed by comparing it with the existing operations software. The agreement between the software suites was at the numerical

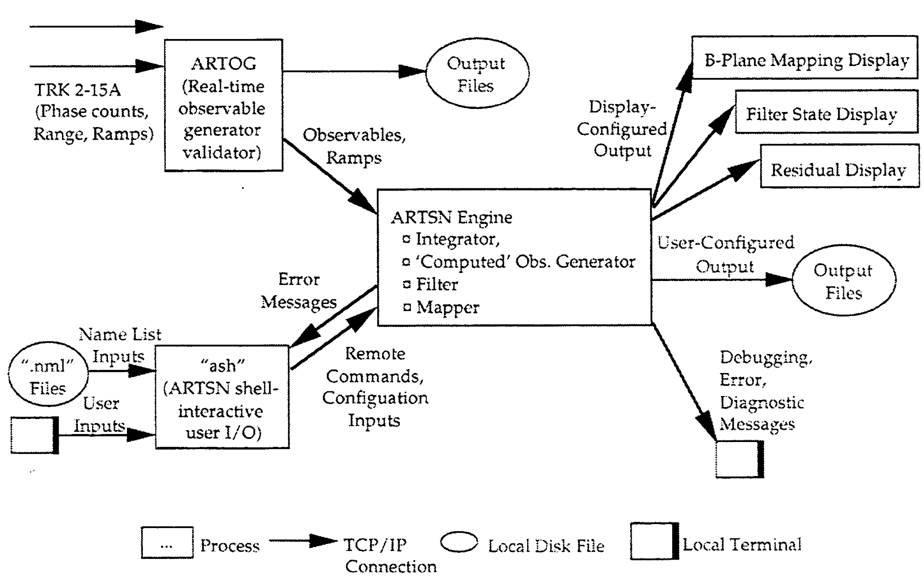

FIGURE 1. ARTSN DATA FLOW DIAGRAM

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Space VLBI Co-Observing at the DSN

RADIO ASTRONOMY

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Introduction

The Space Very Long Baseline Interferometer VLBI (SVLBI) co-observing program, using the Deep Space Network (DSN), was initiated in 1993 under the auspices of the SVLBI Project. because of their superb sensitivity and important strategic location, the DSN 70-m radio telescopes play an important role in the Project's ground-based observing network, which consists of a few tens of radio telescopes around the world. As a partner in this venture, the DSN Science Office provides R&D hardware and software, which enables DSN participation.

The DSN played a key role in enabling Space VLBI. In 1986, the 70-m antenna at the Canberra Deep Space Communications Complex (CDSCC) was the first ground-based radio telescope to participate in the highly successful ground-space VLBI experiments that used the communication satellite TDRSS as the space-borne element, thus demonstrating the viability of the Space VLBI concept. It was clear that the first generation of space VLBI missions — VLBI Space Observatory Programme (VSOP) and RadioAstron — with small, space-based antennas with diameters of 8 and 10 m respectively (not much larger than the TDRSS 4.5-m antenna), would require co-observing support of large, ground-based radio telescopes. The 70-m DSN radio telescopes are among the largest such telescopes in the world.

The Space VLBI mission VSOP was launched on February 12, 1997. After successful deployment, the VSOP mission was renamed Highly Advanced Laboratory for Communications and Astronomy (HALCA). During the first half year, performance of the Earth-to-space interferometer and its elements was extensively tested. The first interferometric fringes at L- and C-band were detected, and the first images of radio sources observed at baselines up to two Earth diameters were published. The HALCA mission is now in its operational stage.

Since the Space VLBI mission forms an interferometer between the Earth-based and space-based radio telescopes, reliable performance of the former is crucial to the mission. To make the DSN 70-m telescopes work reliably and efficiently with the HALCA space radio telescope, the DSN's receiving and VLBI equipment and operations procedures had to be significantly improved.

SVLBI Co-Observations Upgrade Task

The SVLBI upgrade task began in the fall of 1995. It included an upgrade of the DSN's MKIII VLBI recorders to MKIV, improvements of the L-band and K-band receivers, and development of automtion to allow SVLBI co-observing sessions with minimal involvement by DSN personnel.

The DSN VLBI equipment upgrade included changes to the recording hardware (data acquisition terminals — (DATs) — and tape recorders), the VLBI controller and software (PC Field System — PCFS), and the observing script handler (DSN VLBI Scheduling Processor — DSVP). The MKIII DSN DATs and recorders had to be upgraded to provide compatibility with the VSOP VLBI recording modes. The DSN decided to upgrade its MKIII VLBI recorders to the newly developed MKIV recorders, since they had a wider recording band, were better suited to the other DSN VLBI tasks like VLBI geodesy, and were cheaper than the comparable VLBA recorders. Also, the Goddard Space Flight Center (GSFC) and United States Naval Observatory geodetic networks and the European VLBI Network, a major VLBI radio astronomy network, had decided to adopt the MKIV recorders. Use of the MKIV recording systems also allowed the GSFC-developed PCFS to be used as the VLBI controller, instead of having to modify the DSN VLBI controller. To reduce the labor involved in processing files with generic observing instructions into files with specific instructions for the DSN antennas and equipment, software was developed for automatic processing of the VLBI schedule files.

HALCA has three observing frequency bands: L (1612–1720 MHz), C (4.7–5.0 GHz) and K (22.2–22.3 GHz). Two of these bands, L and K, were covered by existing radio astronomy receivers on the 70-m DSN antennas. The SVLBI upgrade task included replacement of the K-band masers by cooled High Electron Mobility Transistor Low Noise Amplifiers (HEMT LNAs), since the HEMT LNAs are simpler to operate and maintain, and refinement and automation of the noise and tone calibrations at both L and K bands

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